X-band RF Structure Fabrication at Technical Division, Fermilab

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Outline

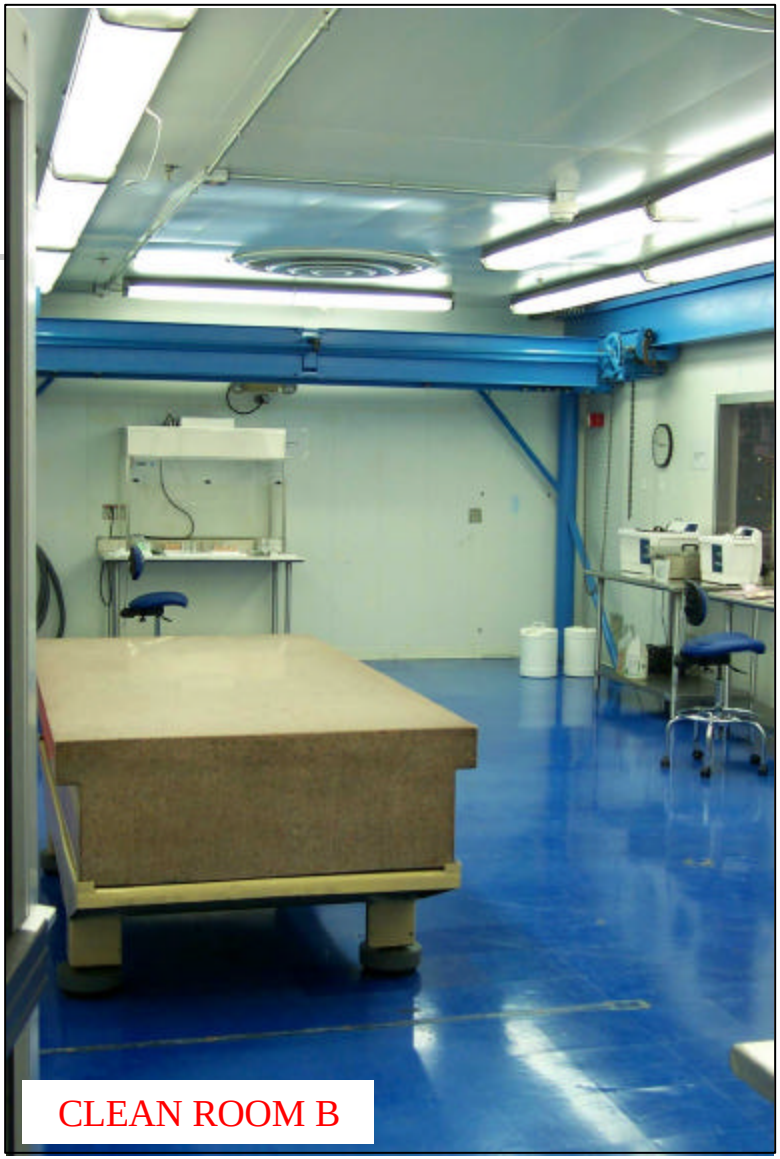
- RF Structure Factory
- Structure fabrication
  - FXA-001
  - FXA-002
- RF Parts & RF Structure mechanical QC
- Lessons learned

RF Structure Factory

- FNAL Technical Division Structure Group's goals for the RF structure R&D factory:
  - RF disk fabrication
  - RF disk quality assurance
  - RF structure fabrication
  - RF structure quality assurance
  - Infrastructure setup for all above
- These are 5 of the 7 elements of the factory (not design, not high power testing)
- Major infrastructure of the factory are:
  - Two clean rooms, RF QC area and a work area
  - Vacuum Furnaces

Clean Rooms

CLEAN ROOM A



CLEAN ROOM B

Clean Room A (Class 5000): RF QC

Clean Room B (Class 1000): Disk assembly, Structure Assembly

Vacuum Furnaces

Small Vacuum Furnace was installed on September 01. Presently in use for RF Structure sub-assembly fabrication and brazing/bonding studies

Large Vacuum Furnace is under construction. It will be delivered to Fermilab on March 02

Structure Fabrication

- OFE C10100 Class I Copper Purchase for RF Disk Fabrication and Peripheral Components:
  - Outokumpu (drawn rod for disks and slabs for couplers)
  - Hitachi (drawn rod for disks)
  - Norddeutsche Affinerie (forged rod for disks)
- All the material is received. (100 ft from each three vendors)
- The stack consists of ten 10-ft long rods
- Sample pieces were sent out for chemical testing. They were inspected and certified with ASTM F-68.
- Sample pieces were hydrogen fired at 1900 ^{o}F for blistering test

Outokumpu Copper Rods for Disk Fabrication

RF Disk & Coupler Fabrication

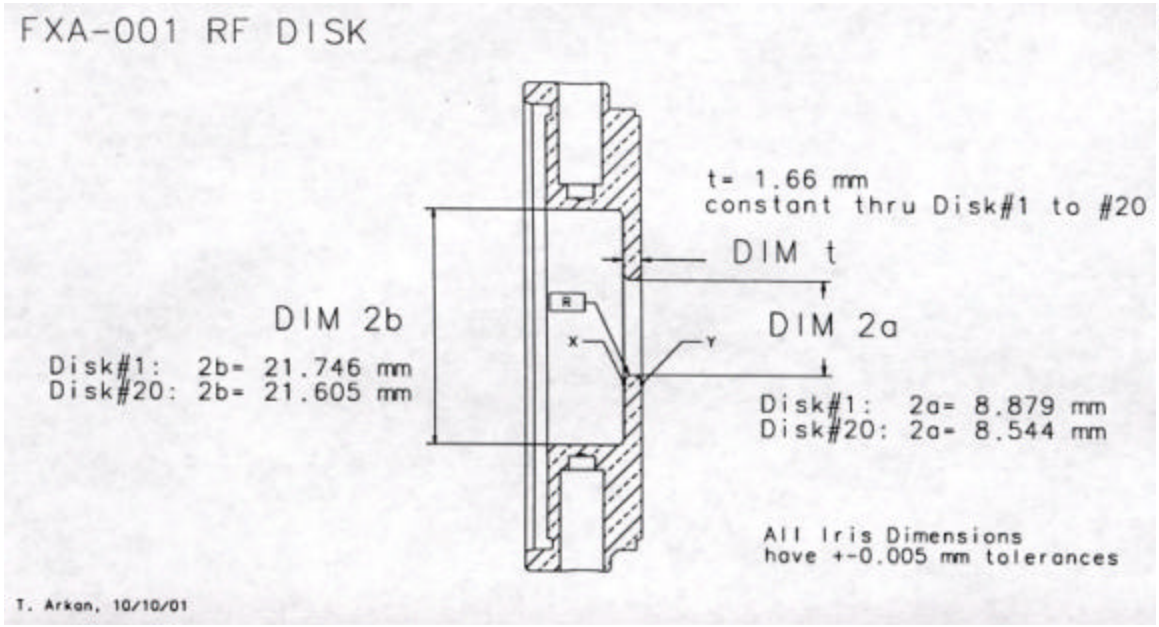
- Outside High Precision and Diamond Turning Machine Shops were used
- There is an existing technology and industry, maximize the competition and minimize the cost
- Identify more local vendors, Always keep the industrialization long term goals in mind
- For FXA-001 and FXA-002:
  - RF Disks from MEDCO, High Precision Machine Shop
  - RF Couplers from CMM, Diamond Turning Shop
- For FXA-003 and beyond (FXB and FXC):
  - 12 other vendors showed interest for both disk and coupler machining

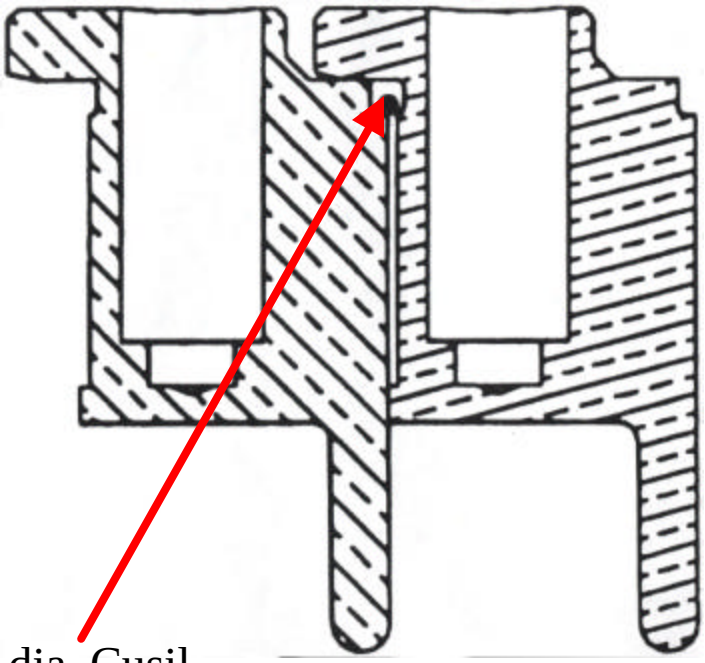
FXA-001 Fabrication - Description

- FXA-001 is the first structure produced by Fermilab
- FXA-001 is a 20-disk high gradient test structure
- Design is Identical to SLAC T20VG5 structure (except for brazing grooves in disks)
- This is an all-brazed structure (no diffusion bonding)
- Disks are precision machined (no diamond turning)
- Couplers are precision machined with some diamond-turned RF surfaces (in the iris area)
- All brazing operations were conducted in a hydrogen furnace at Alpha Braze in Fresno, California

FXA-001 RF Disk Details

- 2a, 2b, thickness (t) and profile of iris.

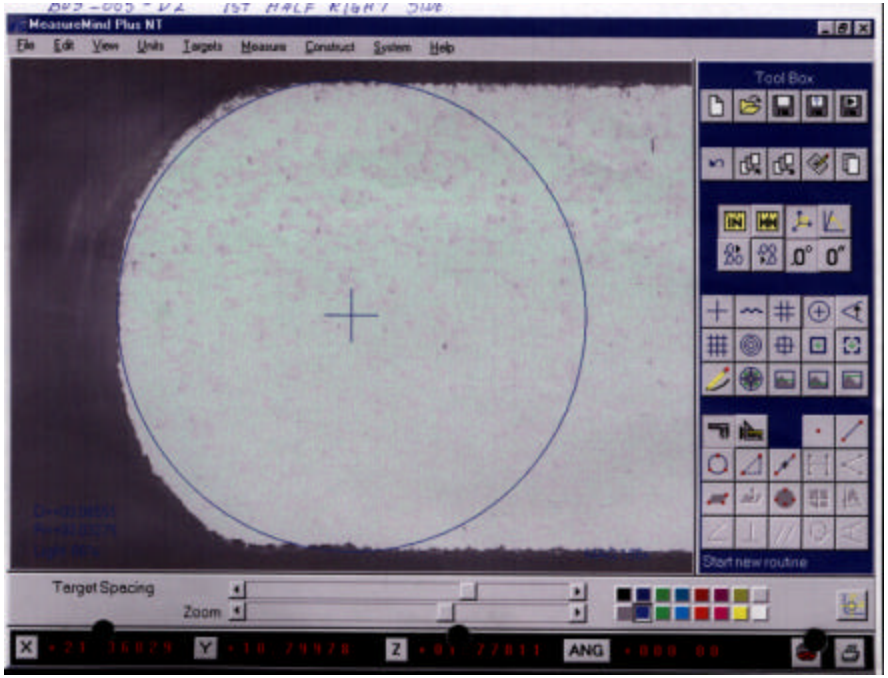




0.75 mm dia. Cusil wire

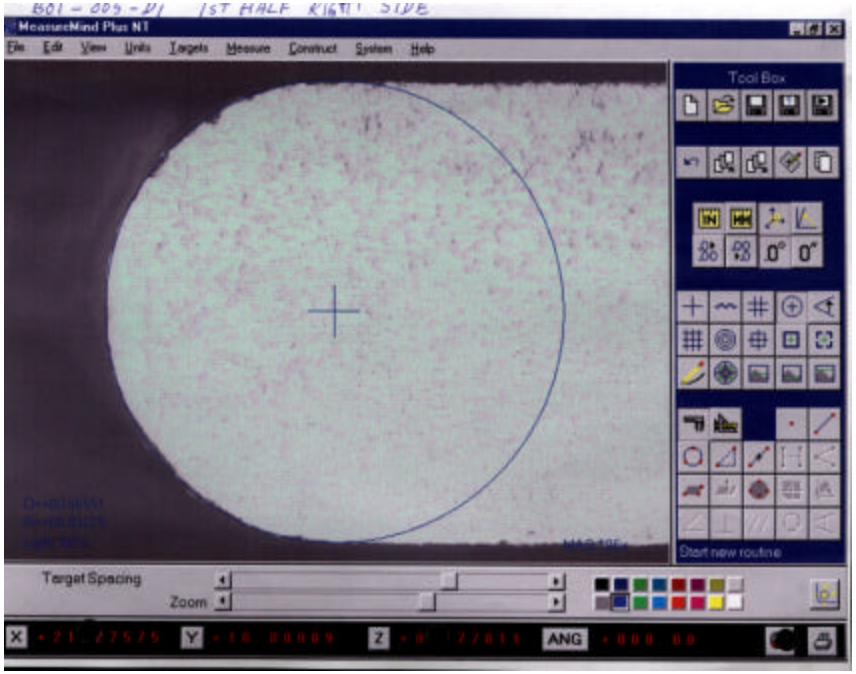
Mechanical QC on RF Disks

Machine: Cordax CMM with a 2.5-micron accuracy



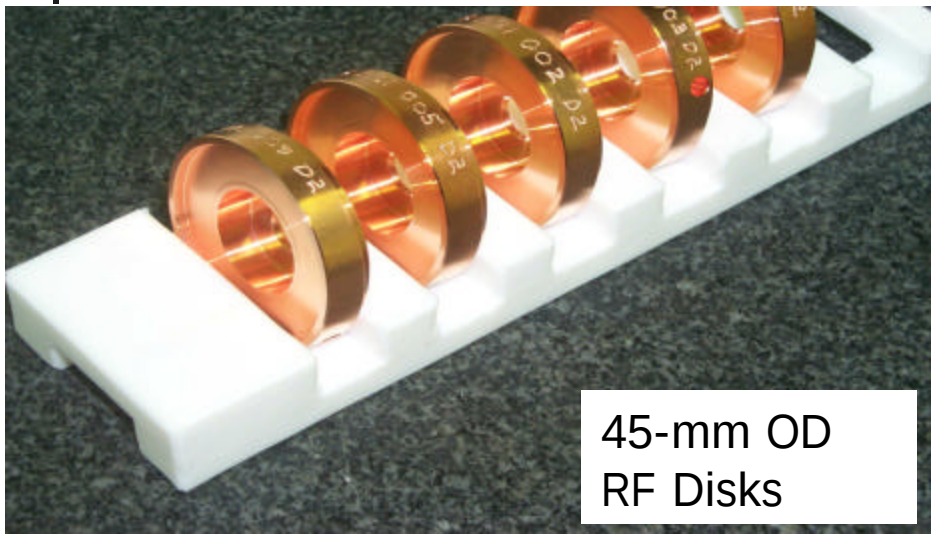
FXA-001 RF Disks
R between X & Y: +50 micron,
Roundness: +55 micron
20 MHz Frequency Error

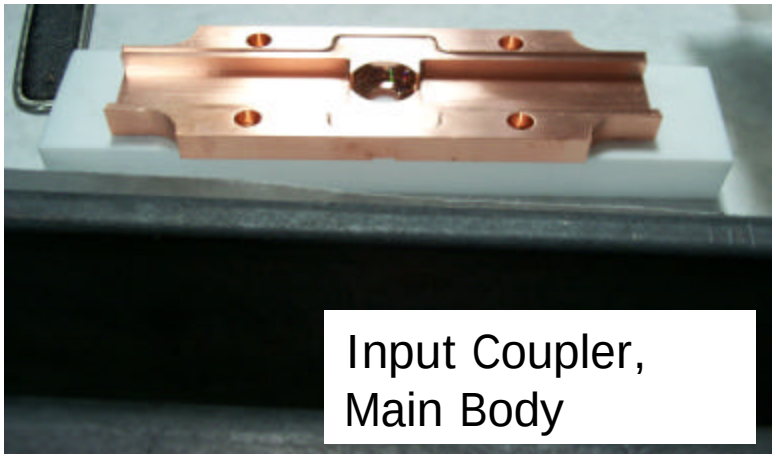
Machine:OGP Optical CMM with a 2.5 micron accuracy

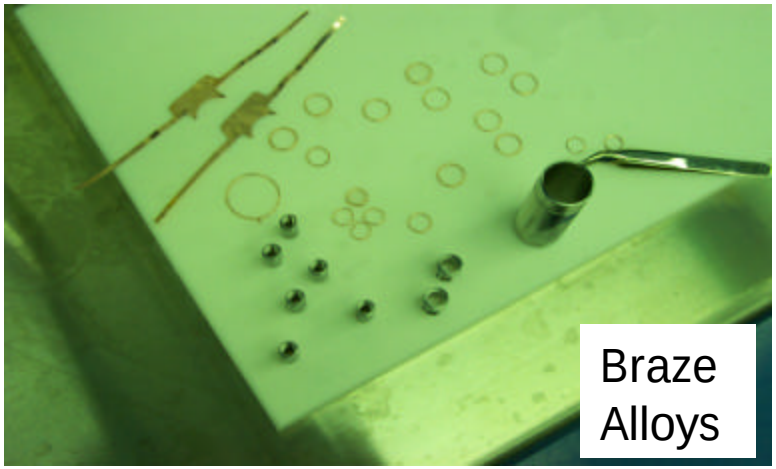


FXA-002 RF Disks
R between X & Y: +3.5 micron,
Roundness: +5 micron
4 MHz Frequency Error

FXA-001 Parts

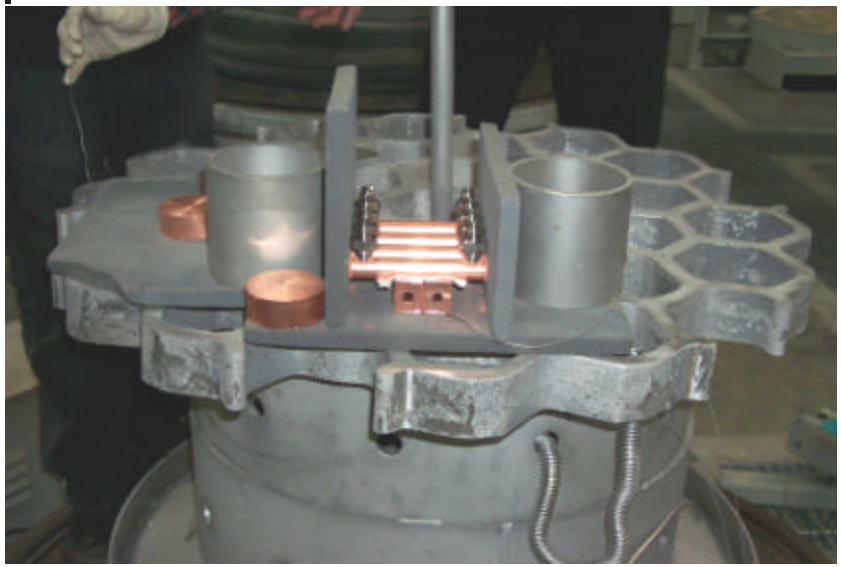






Each RF Disk is scribed with an unique identification number to distinguish, the design, vendor, disk and serial number

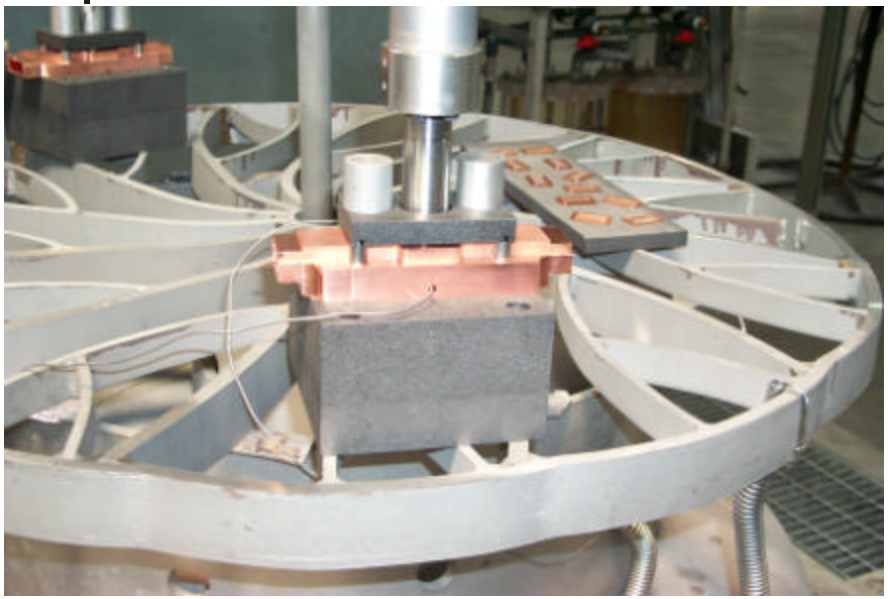
FXA-001 Brazing – Water Tubes



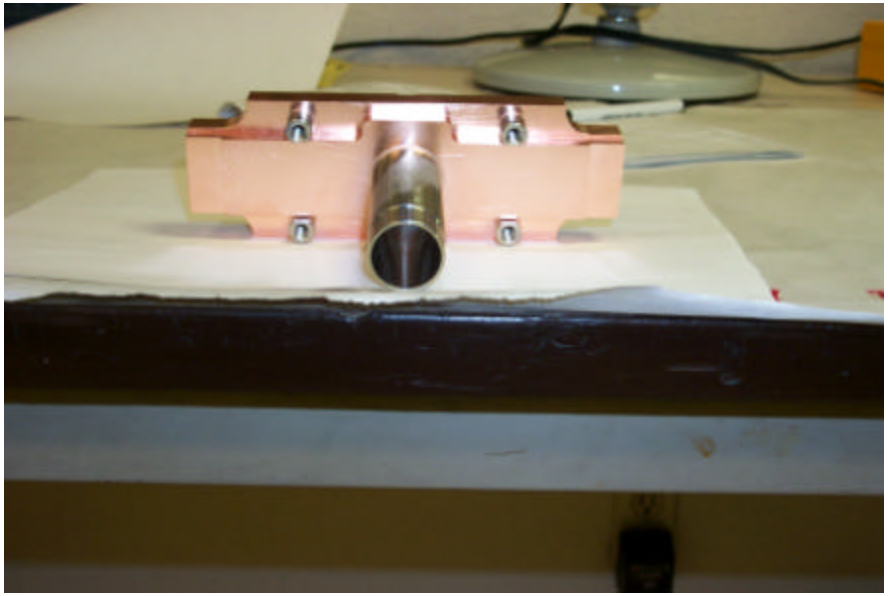
Four Water Cooling Tubes during brazing preparation and in the brazing fixture on the hearth of the furnace

- Brazing Alloy: 35 Gold/65 Copper
- Braze Temp./Time: 1896F / 4 min.

FXA-001 Brazing – Couplers



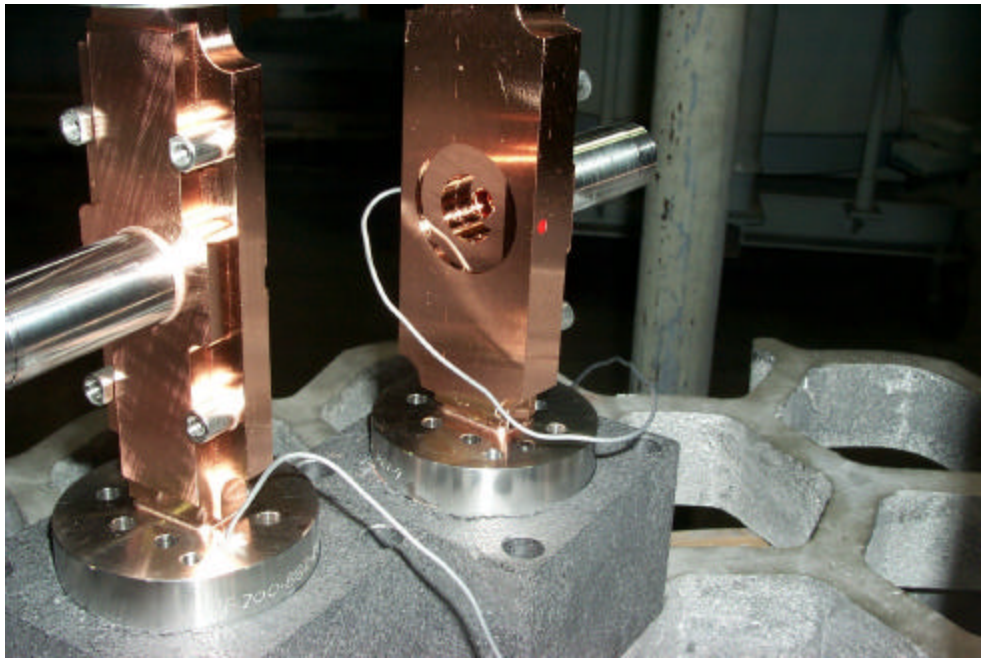
Output Coupler Sub-Assembly in the brazing fixture on the hearth of the furnace



Brazed and Leak Checked completed Output Coupler Sub-Assembly

- Brazing Alloy: 35 Gold/65 Copper
- Braze Temp./Time: 1896F / 4 min.

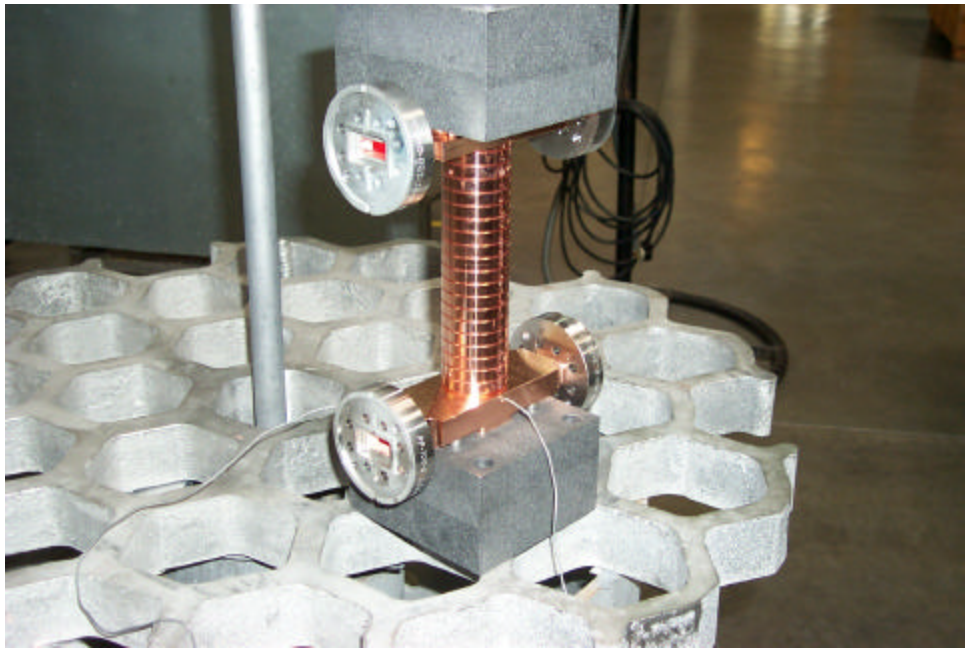
FXA-001 Brazing - RF Flanges



RF Flanges brazing onto the sub-assembled and brazed couplers

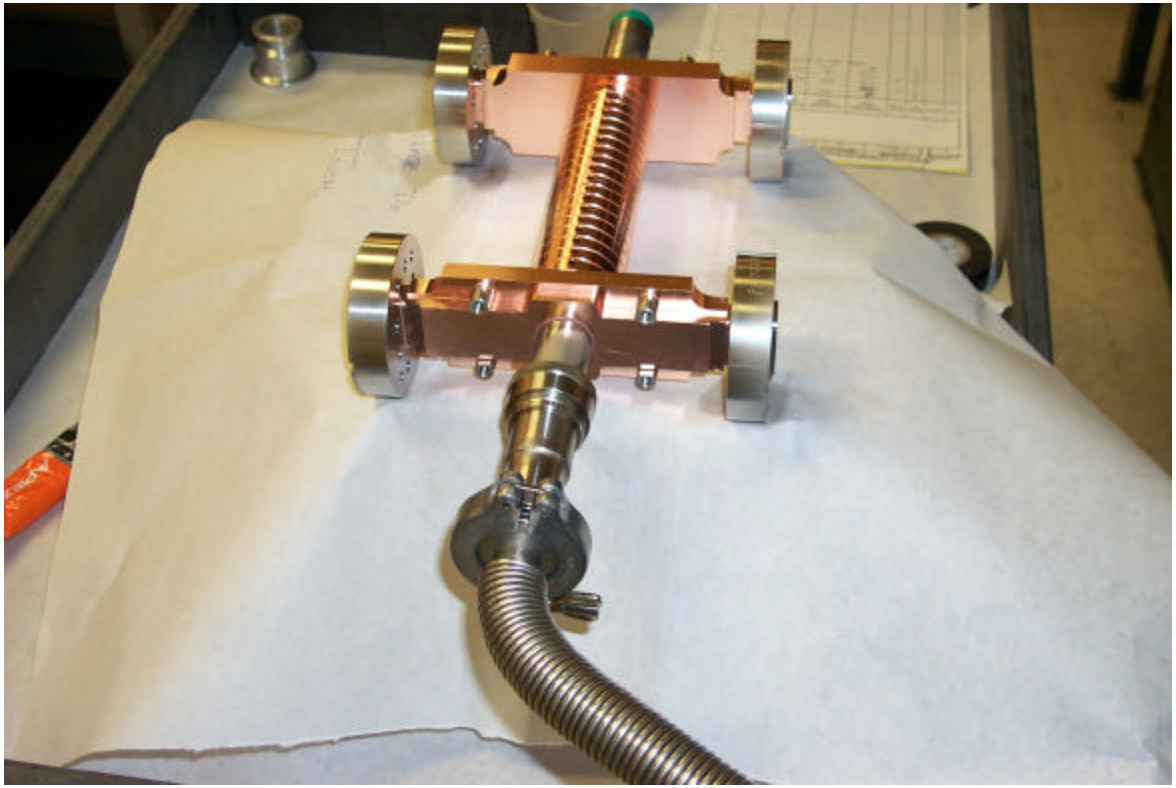
- Brazing Alloy: 50 Gold/50 Copper
- Braze Temp./Time: 1810F / 4 min.

FXA-001 Brazing – Disk Stack



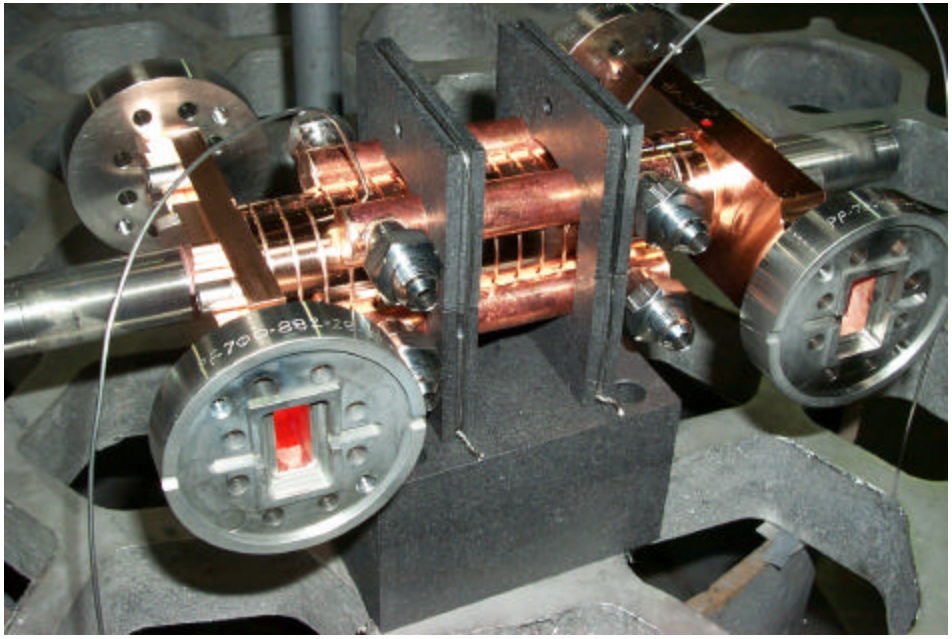
- **Disk Stack & Coupler Brazing**
  - Weight Used: 7lbs. plus Carbon Block
  - Fixturing: Machined Carbon Blocks
  - Brazing Alloy: Cusil (28Cu / 72 Ag)
  - Braze Temp./Time: 1475F / 4 min.

FXA-001 Leak Checking



Leak Check Prior to Brazing Water Cooling Tubes

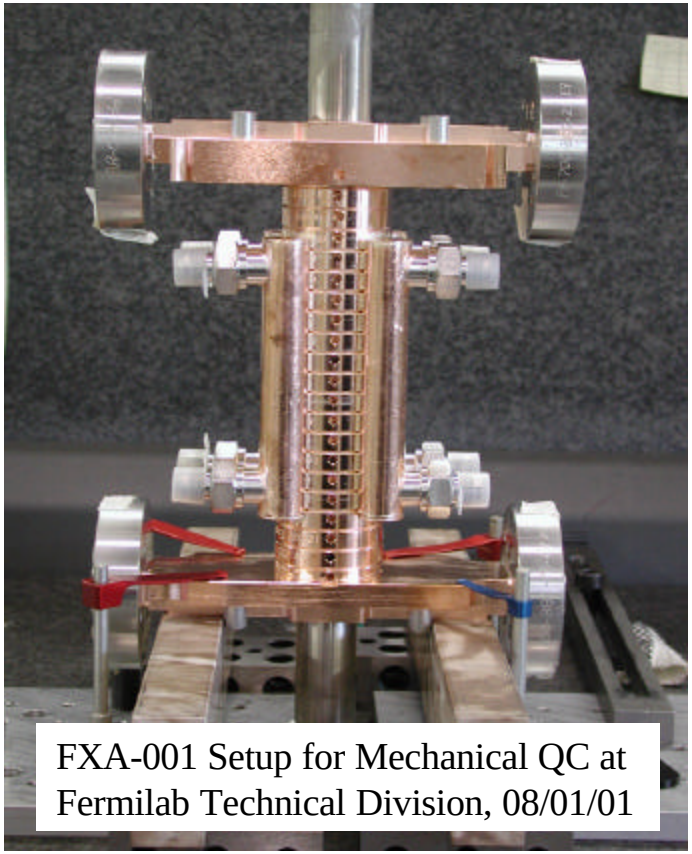
FXA-001 Brazing – Water Tubes



- **Water Cooling Tube-to-Structure Brazing**
  - Brazing Alloy: Incusil (61.5 Ag/ 23.5 Cu/15 In)
  - Braze Temp./Time: 1350F / 4 min.

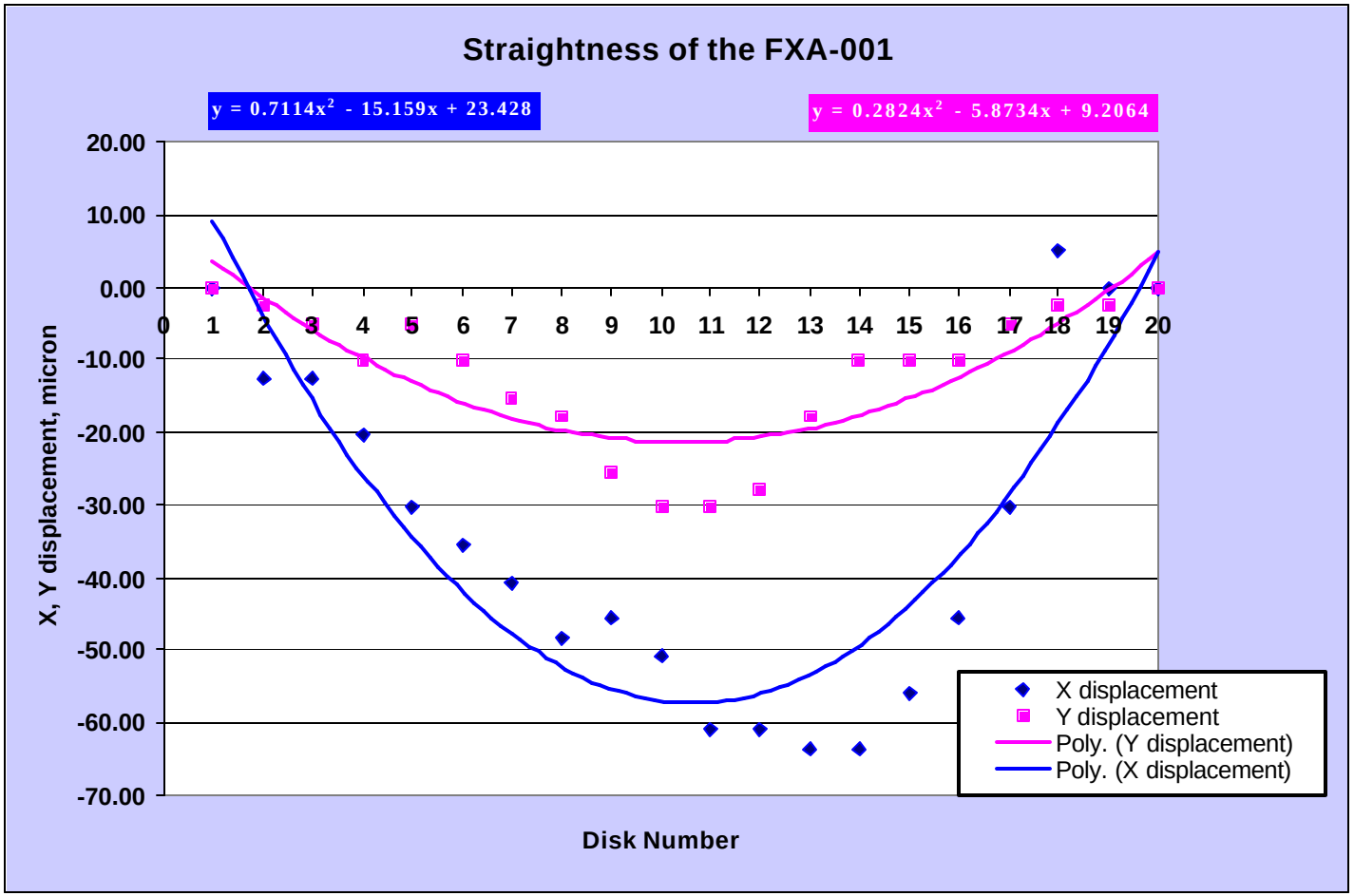
Mechanical Measurements

- Measurements Conducted
  - Structure Straightness
  - Perpendicularity of I/O Couplers to Disk Stack
  - Parallelism of I/O Coupler bodies to cover plates
  - Beam tube concentricity to Disk Stack
  - RF flange perpendicularity to coupler body
  - Rotational alignment of couplers to one another
  - Multiple leak checks

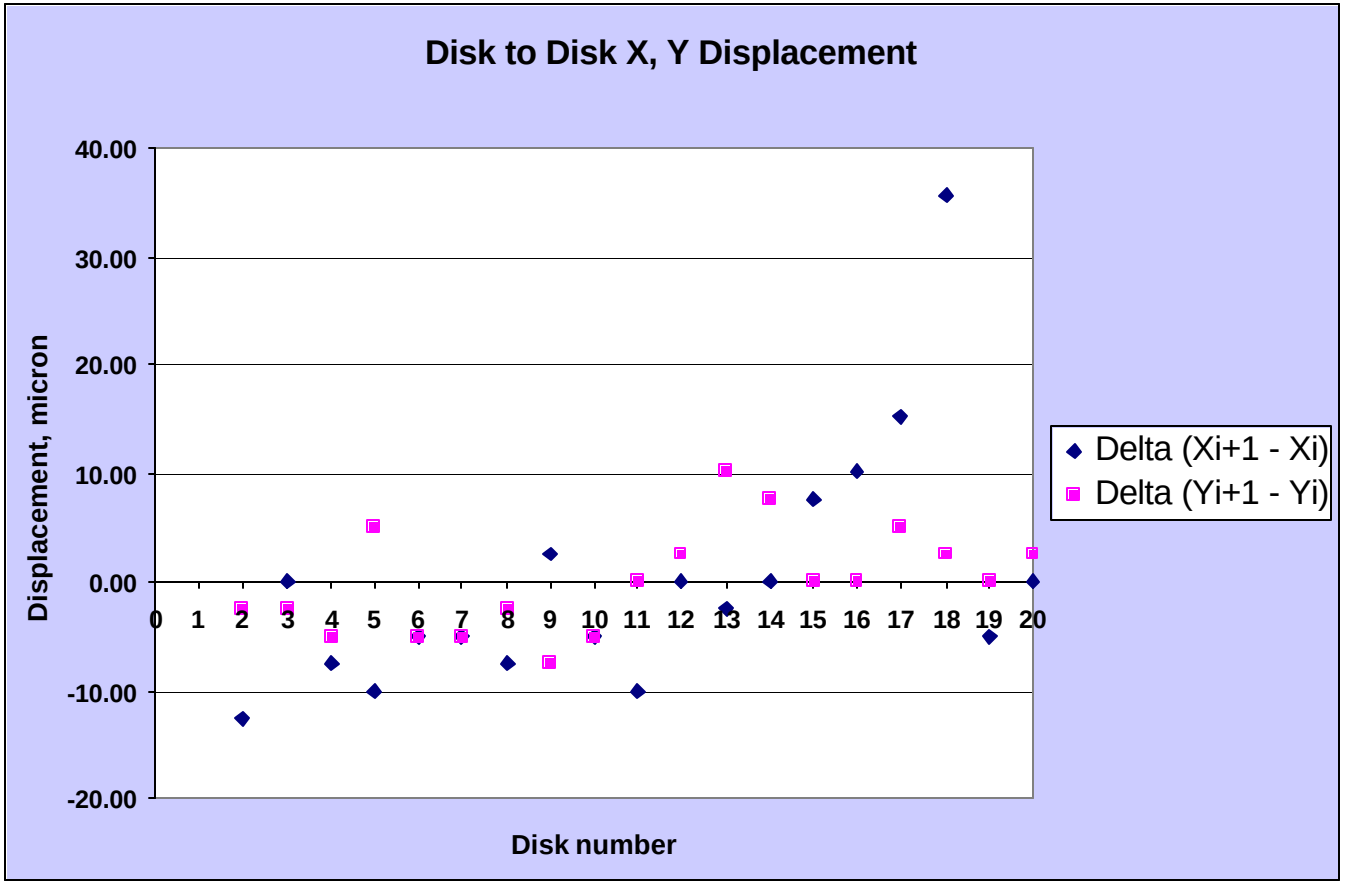


FXA-001 Setup for Mechanical QC at Fermilab Technical Division, 08/01/01

Straightness QC on FXA-001



Disk to Disk Alignment of FXA-001



Lessons Learned from FXA-001

- We must work closely with the RF disk suppliers to help them produce better disks, better tolerance holding and better electrical performance
- We must find more vendors to machine RF Couplers. Couplers are very expensive and very difficult parts to be machined by design. Long lead time for delivery.
- We must improve communications and technical information transfer between FNAL and SLAC
- We must develop technical specifications, assembly procedures, parts cleaning procedures, and quality assurance procedures in order to reliably produce high quality, high performance structures

FXA-001 Fabrication Chronology

OPERATION	START	END
Part Procurement	October 2000	February 2001
Brazing Tests	February 2001	April 2001
Sub-Assemblies Brazing	March 2001	April 2001
Complete FXA-001 Brazing	May 2001	May 2001
Mechanical & RF QC	June 2001	August 2001
Structure Completed		September 2001

FXA-002 Fabrication

- From FXA-001 to FXA-002:
  - Small Furnace installed and used to make sub-assemblies for FXA-002
    - Due to sublimation effects, braze alloys melt in a lower temperature than 1 Atm normal conditions. Brazing Alloys melting temperature studies were conducted at 150 mTorr Argon partial pressure
  - RF Disks from MEDCO were optimized by:
    - Fixing the iris profile error
    - Machining repeatability improvement
    - Biasing 2b dimension tolerance so that we do not have to braze tuning studs
    - Ordering extra disks for mechanical QC for the machine shop and also for us. (No mechanical QC on actual disks)
  - Assembly Technique and Fixturing:
    - Revised assembly sequence to improve accuracy
    - Improved fixturing to improve assembly accuracy
  - RF part cleaning and etching with SLAC's procedure

FXA-002 Fabrication - Description

- FXA-002 is the second structure produced by Fermilab
- FXA-002 is a 20-disk high gradient test structure
- Design is Identical to SLAC T20VG5 structure (except for brazing grooves in disks).
- It is identical to FXA-001 with fabrication process and tooling improvements
- This is an all-brazed structure (no diffusion bonding)
- Disks are precision machined (no diamond turning)
- Couplers are precision machined with some diamond-turned RF surfaces (in the iris area)
- RF Parts were cleaned & etched with SLAC's procedure
- Sub-Assembly (Couplers, Water Tubes) brazing of the structure were conducted in our new small vacuum furnace at Fermilab.
- Final brazing operations (RF Disk Stack to Couplers and Water to tubes to RF Disk Stack) were conducted in a vacuum furnace at Alpha Braze in Fresno, California
- Structure will not be exposed to Hydrogen during brazing

Assembly Approach for FXA-002

- Water Tubes:

Water Tube Sub-Assembly Brazing (35%Au + 65%Cu)

Vacuum Leak Check, no Hydrostatic test

- Input Coupler:

Input Coupler Sub-Assembly (35%Au + 65%Cu)

Vacuum Leak Check

Machine the ends of the Input Coupler Sub-Assembly

Mechanical QC

RF Flanges to Input Coupler Sub-Assembly (35%Au + 65%Cu)

Vacuum Leak Check

RF QC

Disk#1 to Input Coupler Sub-Assembly (50%Cu + 50%Au)

Vacuum Leak Check

Assembly Approach for FXA-002

- Output Coupler:

Output Coupler Sub-Assembly (35%Cu + 65%Au)
Vacuum Leak Check
Machine the ends of the Output Coupler Sub-Assembly
Mechanical QC
RF Flanges to Output Coupler Sub-Assembly (35%Cu + 65%Au)
Vacuum Leak Check
RF QC
Disk#20 to Output Coupler Sub-Assembly (50%Cu + 50%Au)
Vacuum Leak Check

- RF Disk Stack – 18 Disks:

Braze 18 RF Disks (Disk #2 to Disk #19) (Cusil)
Vacuum Leak Check
Mechanical QC, RF QC

Assembly Approach for FXA-002

- RF Disk Stack to Couplers (Alpha Braze)

RF Disk Stack Sub-Assembly to the Input/Output Coupler Sub-Assembly (Cusil)

Vacuum Leak Check

- Water Tubes on the Structure: (Alpha Braze)

4 Water Tubes to the Structure (Couplers and Disks brazed) (Incusil)

Vacuum Leak Check

- Final QC: (to be completed by 02/15/02)

Vacuum Leak Check the Completed Structure

Mechanical QC on the Completed Structure

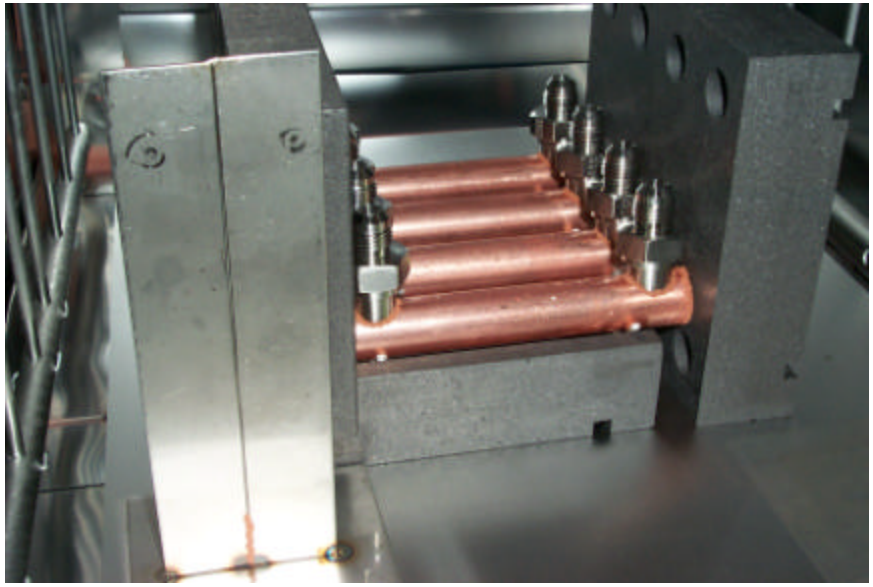
Disk Stack Straightness

Disk to Disk Alignment

Couplers parallelism to each other and perpendicularity to the disk stack

RF QC

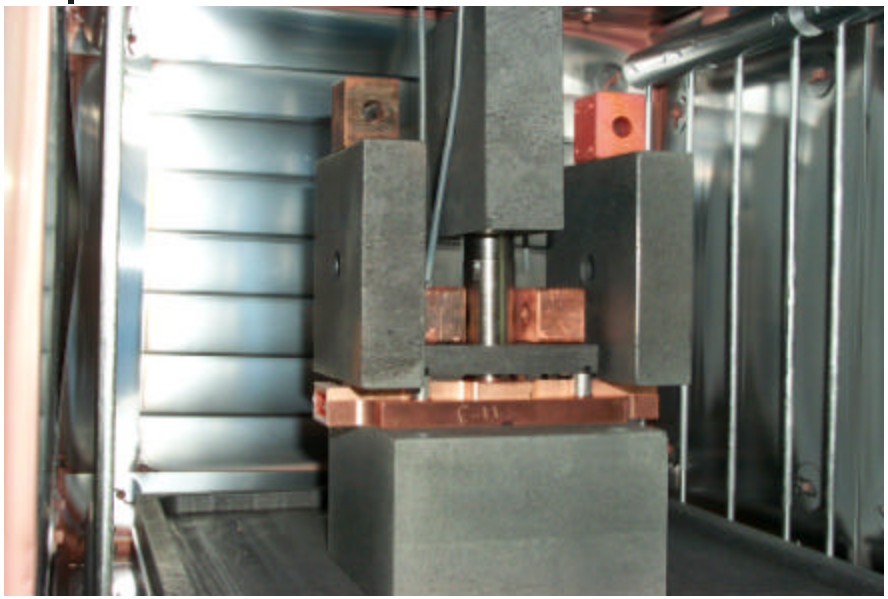
FXA-002 Brazing – Water Tubes



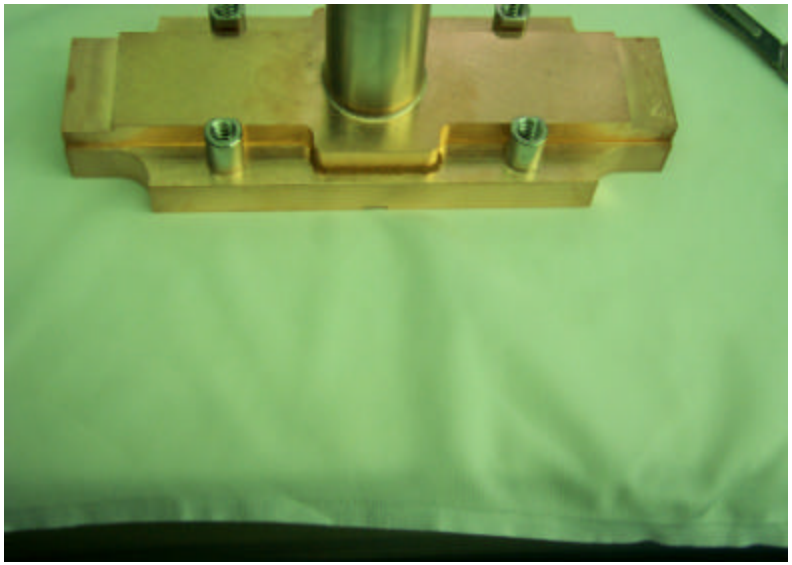
Four Water Cooling Tubes assembled onto the brazing fixture in the FNAL small vacuum furnace

- Brazing Alloy: 35 Gold/65 Copper
- Braze Temp./Time: 1774F / 4 min.

FXA-002 Brazing – Couplers



Output Coupler Sub-Assembly in the brazing fixture on the hearth of the FNAL vacuum furnace

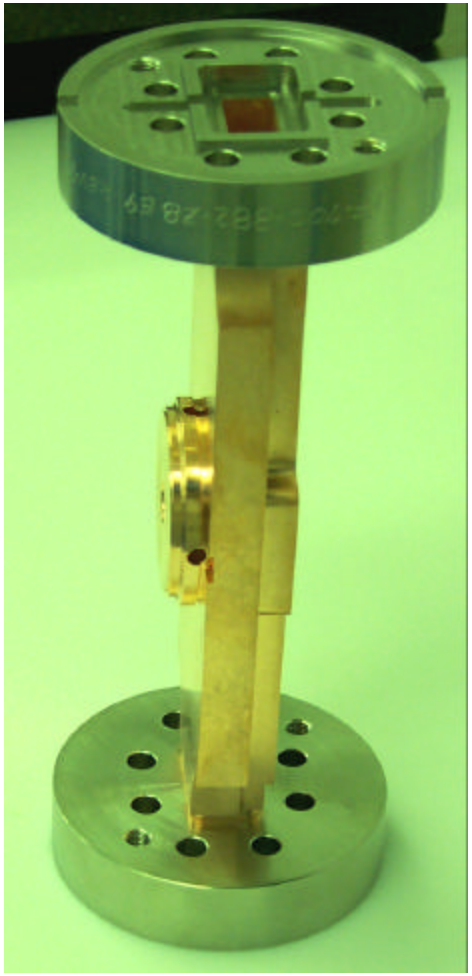


Brazed and Leak Checked completed Input Coupler Sub-Assembly

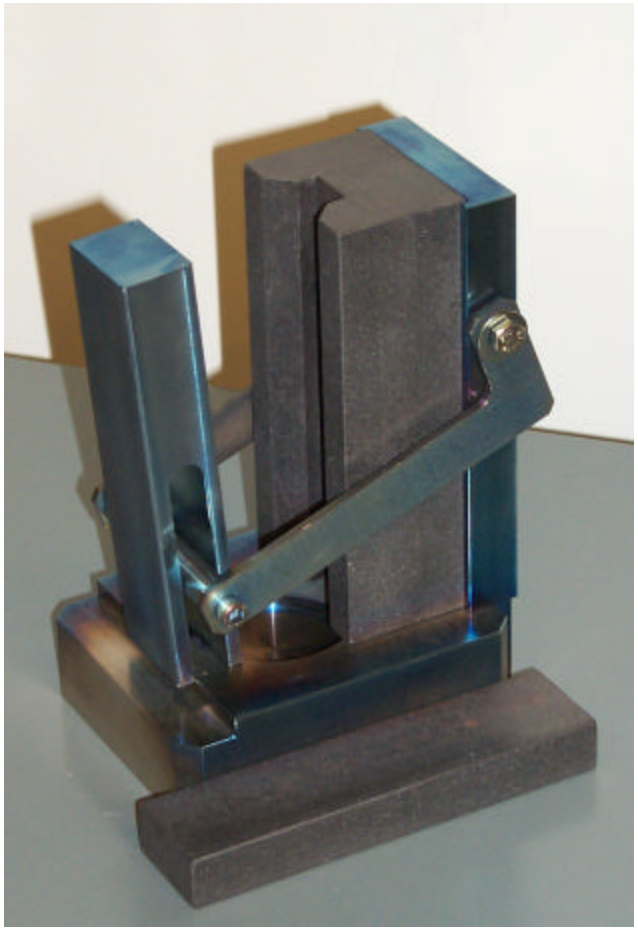
- Brazing Alloy: 35 Gold/65 Copper
- Braze Temp./Time: 1774F / 4 min.

FXA-002 Brazing – First&Last Disk

- **First & Last Disk Brazing**
  - First disk was brazed onto the input coupler. Last disk was brazed onto the output coupler
  - Better RF flange perpendicularity to coupler body
  - FNAL Small Vacuum Furnace is used
  - Brazing Alloy: 50%Cu +50%Au
  - Braze Temp./Time: 1700F / 4 min.

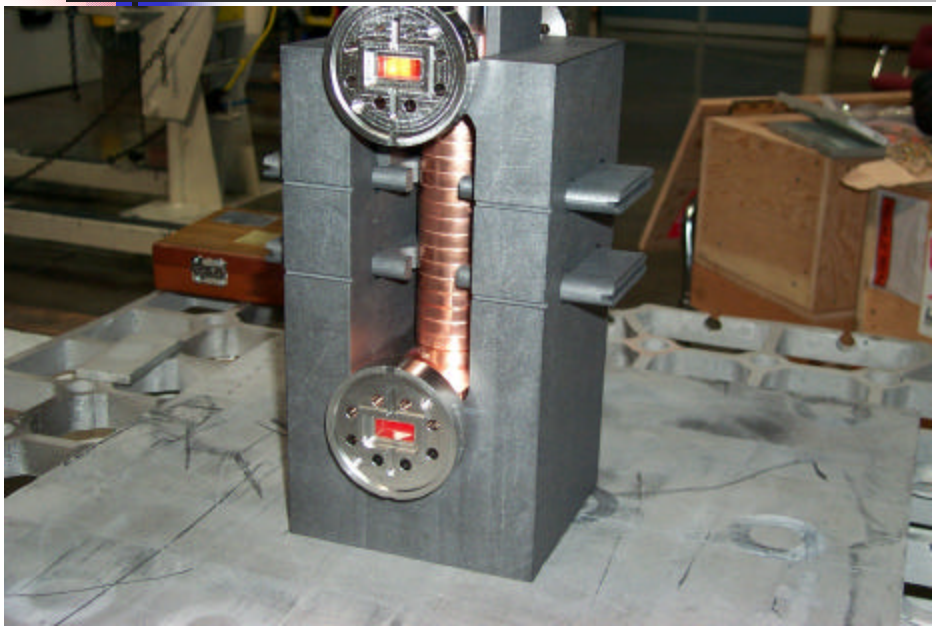


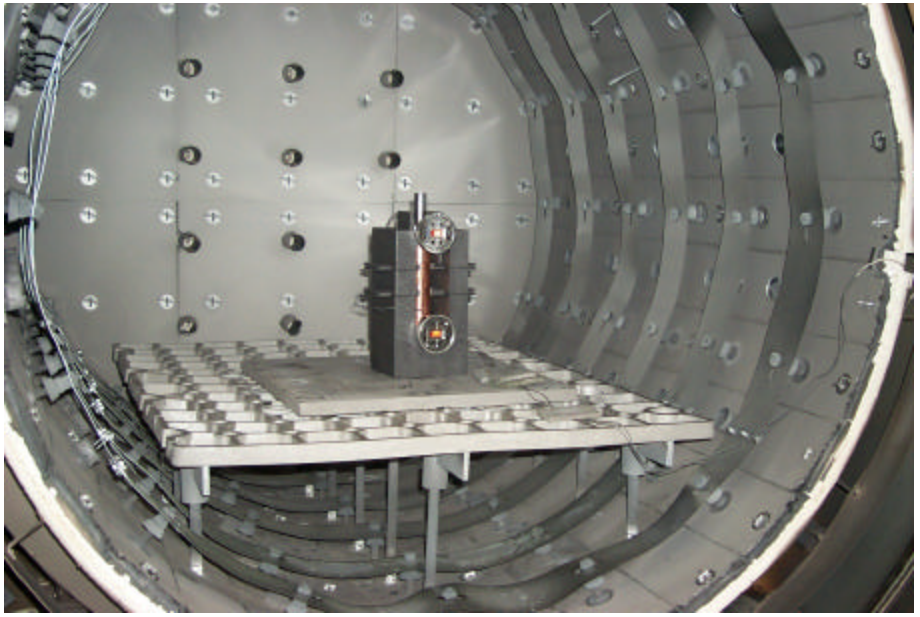
FXA-002 Brazing – Disk Stack



- **Disk Stack Brazing**
  - New Fixture for better disk to disk alignment
  - FNAL Small Vacuum Furnace is used
  - Brazing Alloy: Cusil (28Cu / 72 Ag)
  - Braze Temp./Time: 1353F / 4 min.

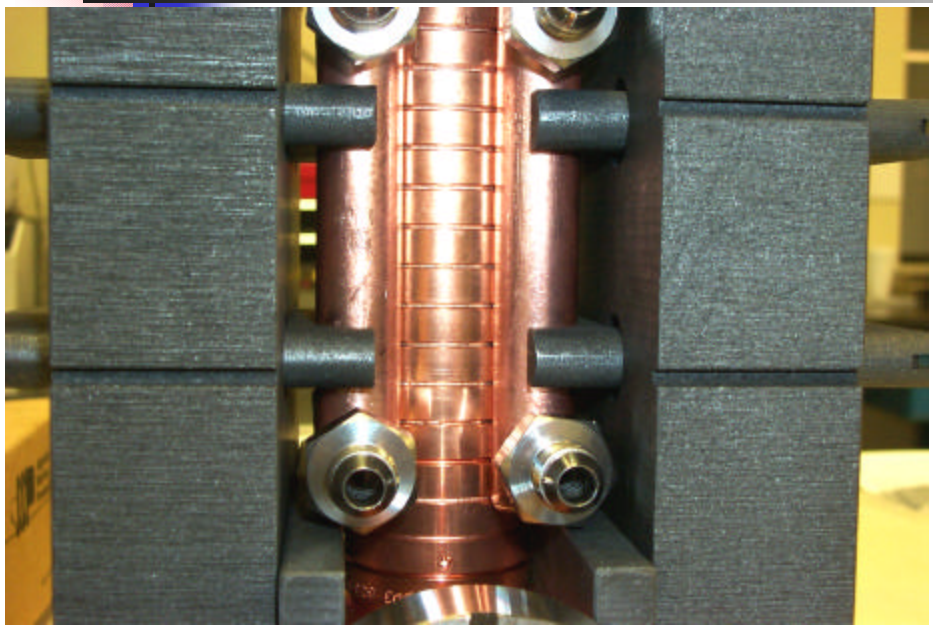
FXA-002 Brazing – Disk Stack to Couplers

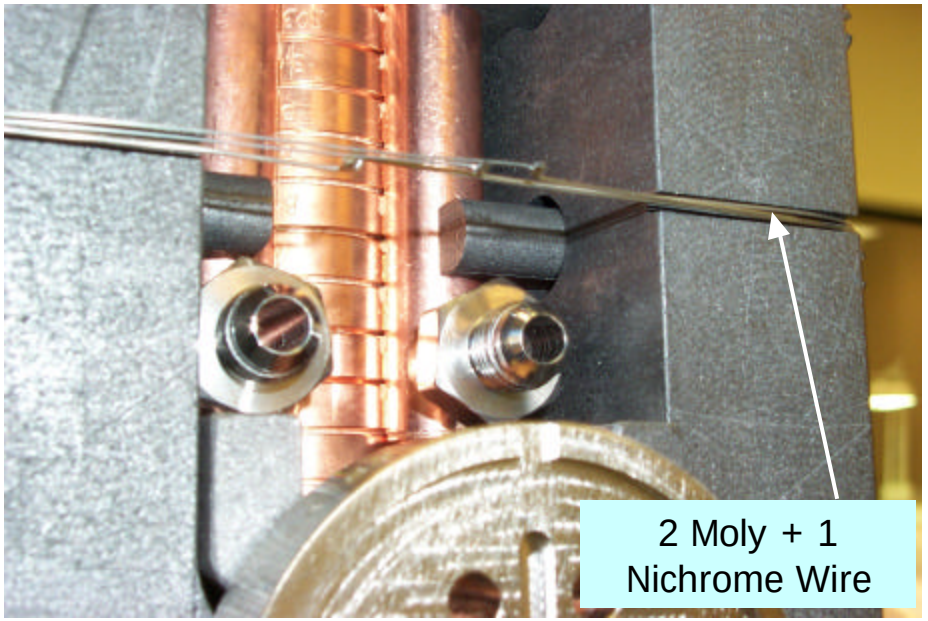




- **Disk Stack to Coupler Brazing**
  - New Fixture for better Input/Output Coupler rotational alignment
  - Vacuum Furnace at Alpha Braze is used
  - Brazing Alloy: Cusil (28Cu / 72 Ag)
  - Braze Temp./Time: 1353F / 4 min.

FXA-002 Brazing – Water Tubes

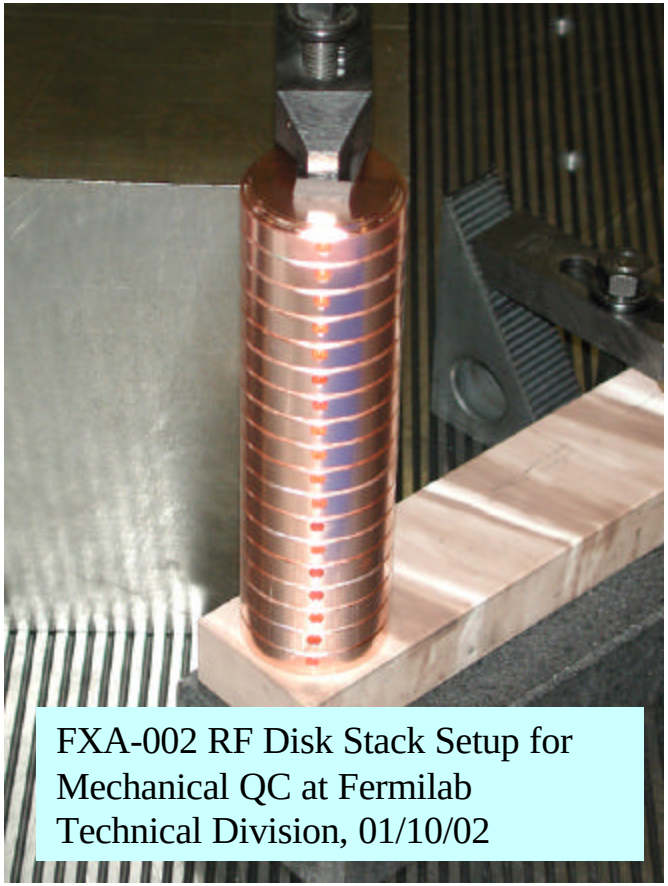




- **Water Cooling Tube-to-Structure Brazing**
  - New Fixture allowing to braze water tubes vertically. Possible sag problem prevention during final brazing
  - Vacuum Furnace at Alpha Braze is used
  - Brazing Alloy: Incusil (61.5 Ag/ 23.5 Cu/15 In);Braze Temp./Time: 1228F / 4min.

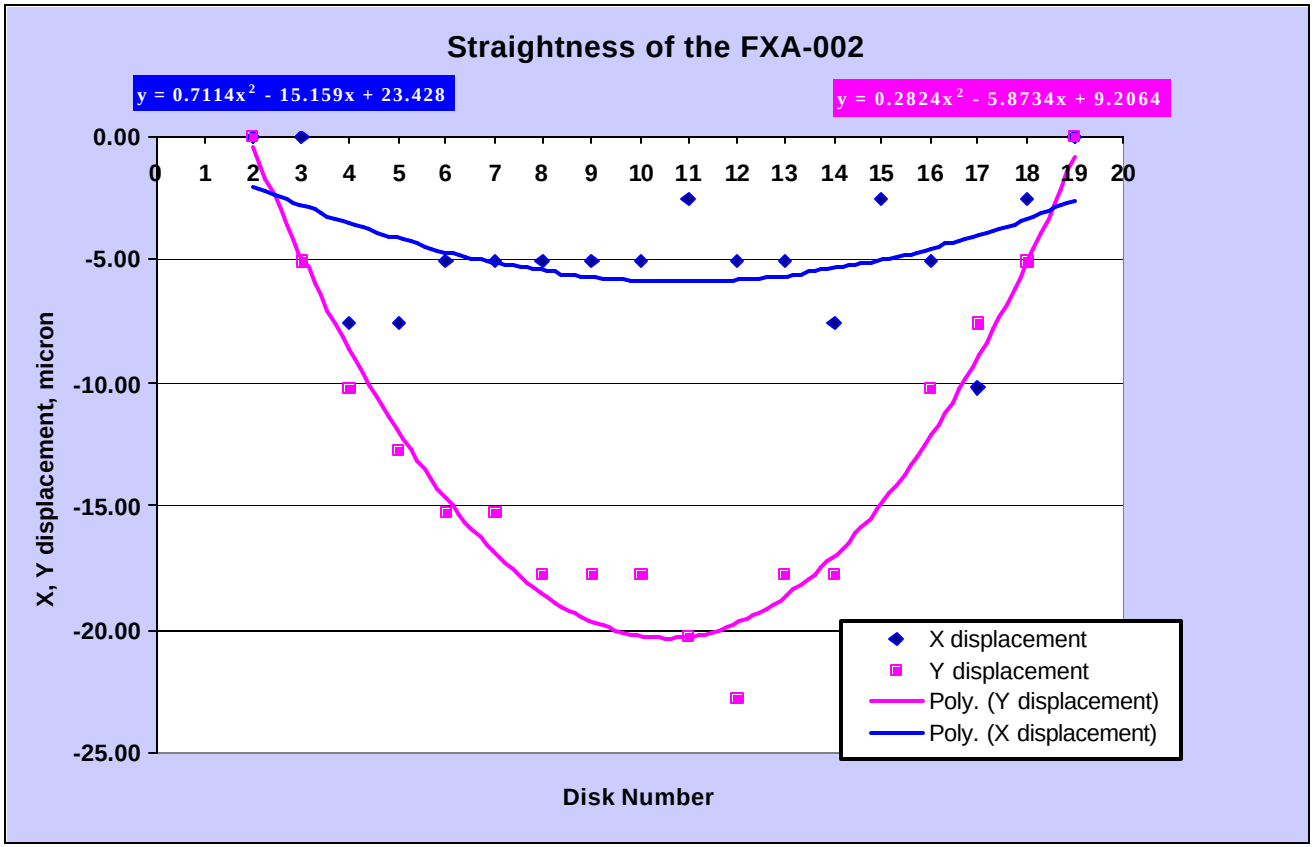
Mechanical Measurements

- Measurements Conducted:
  - Disk Stack Straightness
- Measurement to be Conducted on the completed FXA-002 Structure:
  - Structure Straightness
  - Perpendicularity of I/O Couplers to Disk Stack
  - Parallelism of I/O Coupler bodies to cover plates
  - RF flange perpendicularity to coupler body
  - Rotational alignment of couplers to one another

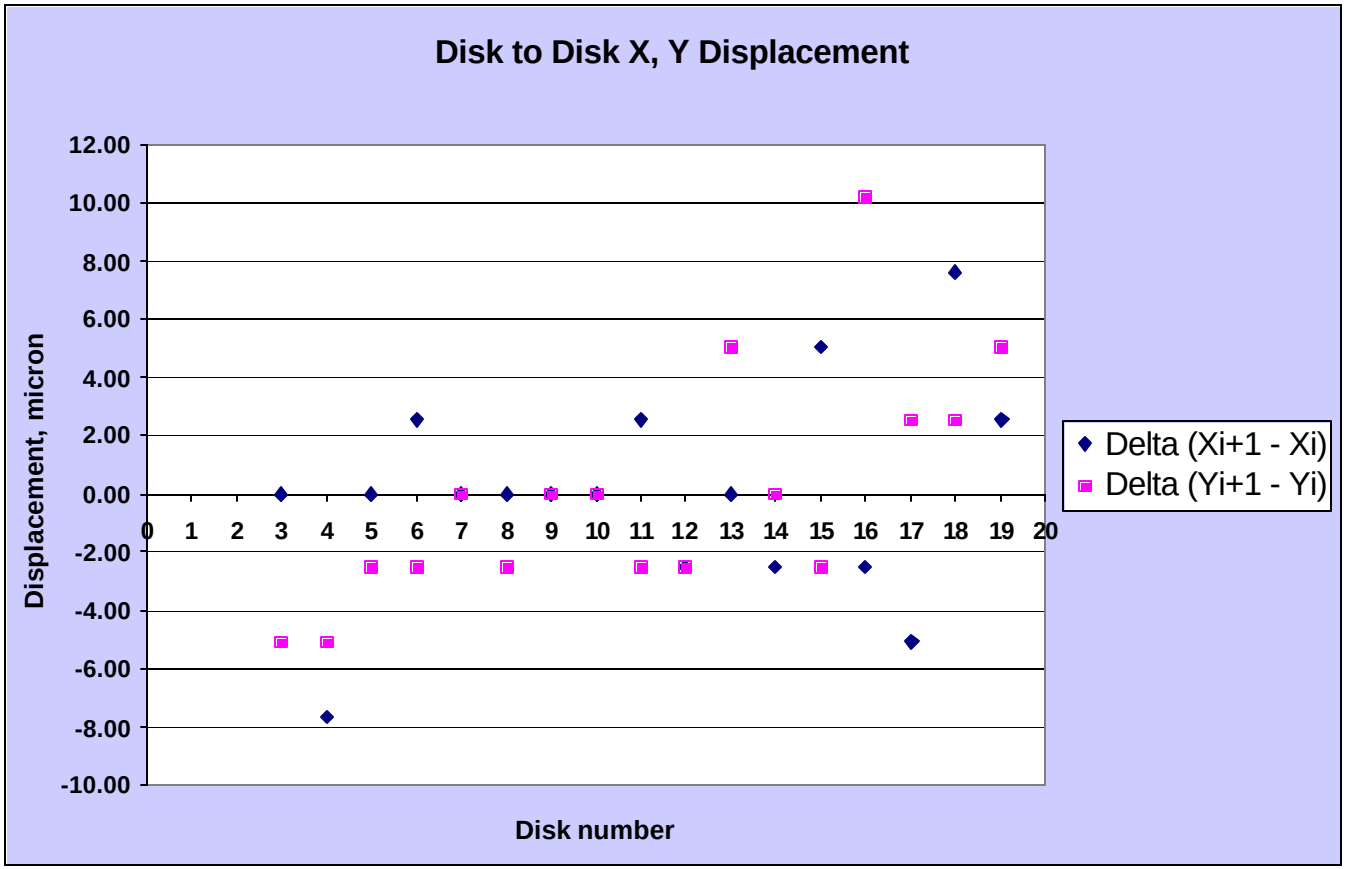


FXA-002 RF Disk Stack Setup for Mechanical QC at Fermilab Technical Division, 01/10/02

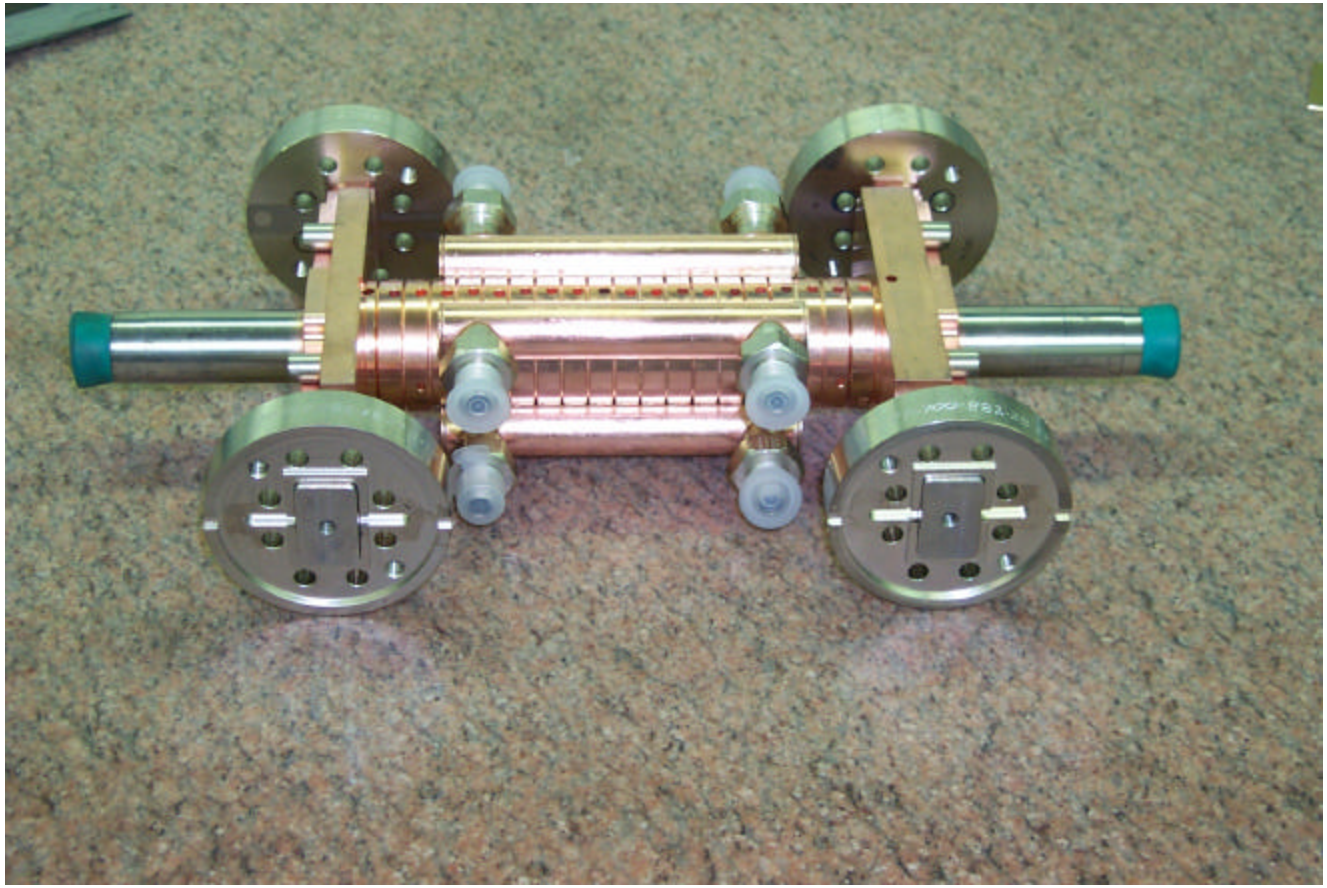
Straightness QC on FXA-002 RF Disk Stack



Disk to Disk Alignment of FXA-002 RF Disk Stack



Completed FXA-002



FXA-002 Fabrication Chronology

OPERATION	START	END
Part Procurement	September 2001	November 2001
Brazing-Furnace Tests	November 2001	December 2001
Sub-Assemblies Brazing	Jan 02, 2002	Jan 25, 2002
Complete FXA-001 Brazing	Jan 29, 2002	Jan 31, 2002
Mechanical & RF QC	Feb 04, 2002	
Structure Completed		

Lessons Learned from FXA-002

- Braze Alloys melting behavior at High Vacuum Atmospheres
- For the same braze alloy at same temperature and pressure:
  - T_powder < T_wire < T_foil
- We have to get our vacuum furnaces calibrated by at outside contractor periodically
- We have to optimize etching vs. sacrifice of the good surface finish
- There is still room for improvement for RF Disk fabrication. Work closely with vendors and have better product for FXB structures
- We proved that we can finish the brazing assembly of the structure in 1 month assuming that all the parts are in house
- We must develop technical specifications, assembly procedures, parts cleaning procedures, and quality assurance procedures in order to reliably produce high quality, high performance structures